Noname manuscript No.
(will be inserted by the editor)

Analyzing Diversity, Strength and Centrality of Cities using Networks of Multinational Firms

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Received: date / Accepted: date

Abstract Cities play an important role in the regional, national and continental development of economies, as well as global trade and infrastructure. Most of this development revolves around the presence of multinational firms and the inter-connected systems formed by their linkages. Analyzing the networks formed by these multinational firms can uncover many interesting trends and patterns providing insight into not only the development of individual cities, but also the various world regions they belong to.

In this paper, we are particularly interested in networks of cities from the year 2010 and 2013 in order to understand how cities have changed in the context of networks of multinational firms. We consider diversity, strength and centrality as the key indicators to measure the importance of a city and based on these indicators analyze how cities have changed their roles in the networks of multinational firms overtime. We also introduce a cumulative ranking based on these three indicators to position cities in terms of their importance in the world. This study not only strengthens previous findings from a network analysis perspective but it also reveals the cities with considerable growth and/or significant decline over the periods studied.

Keywords Complex Networks · World Cities · Multinational Firms · Influence Mining · Social Network Analysis

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1 Introduction

The presence of multinational firms plays an important role in the economic development of cities and regions[41,56]. The economic and financial ties of these firms create linkages among cities irrespective of national and continental borders which eventually drive domestic and world economies[17,45]. The strong ties among the trio of New York-London-Tokyo is a good manifestation of this phenomena[43] as intense economic ties exist despite the geographic distances among them.

These linkages among cities often form complex networks[54,4,15,51]. These ties or relations have high significance as they cause high interdependence between cities: a crisis in a city will impact highly the other cities to which it is well connected. This opens up an important dimension in studying these networks, which is to identify important or critical nodes. Identification of these critical nodes has attracted a lot of research activity from various domains such as ranking individuals in social networks[53,12], identifying Achilles heel in power grid networks[30], immunizing potential spreaders to avoid epidemics[35], identifying brideges in a collection of web pages [57] and studying criticality in transportation networks [48,10,37]. Researchers have also used the terms *influence*[29], *power*[9], *central*[19] to represent the concept of *importance*[1] depending on the context it is being used in.

Several methods and techniques have been proposed to identify these critical nodes in large complex networks. These methods generally use network structure to calculate metrics to reveal the importance of a node. Different metrics reveal various aspects of the network structure often revealing critical or influential nodes in certain contexts. For example, the cities which are most critical can be the ones with the highest number of direct connections to other cities, or be strategically located in a network to influence other cities.

In the context of networks of cities, we identify three indicators to explore these networks: *Diversity*, *Strength* and *Centrality*. Each of these measures captures a different notion of importance in a network and details are presented in section 4. In order to find important cities considering all three indicators combined, we introduce a cumulative metric which is a composite of *Diversity*, *Strength* and *Centrality*. The proposed metric reveals the cities which are critical across the two networks as well as the cities which have either increased or decreased their importance during the years from 2010 and 2013. The changes in the importance of a city demonstrate the focus of economic shift that took place in the aftermath of the economic crisis in 2008. As the world economy continues to change with new markets competing with existing economies, this study provides an interesting insight to the change occurring between the 2010 and 2013. Based on our findings, we ascertain the position of several major cities in the world's economy as well as discover some of the developing cities and regions based on multinational firms across the globe.

[1] Throughout this paper, we interchangeably use the terms critical, influential, powerful and central, all representing the concept of important nodes in a network.

The paper is organized as follows: Section 2 reviews the literature. We describe the data in section 3 followed by details of the metrics used and the experimental set-up in section 4. We discuss the results in section 5 and we conclude in section 6 providing future research directions.

2 Related Work

The role of cities has been extensively studied in the context of economic development and trade [8]. For example, the importance of agglomerated cities and regions in the economic development has been well advocated[47,46]. There are several perspectives to study networks of cities, like hierarchical tendencies and regional patterns[13,32]. The studies tried to uncover a hierarchical organization of cities based on their importance and influence. Several other studies have tried to classify cities according to their roles and structural localization in multinational firm networks[49,50,13,1]. Another perspective in the study of these networks of cities is to focus on high spatial concentration of economic and financial hubs [44,45]. Emerging cities and regions in the context of service producing firms has been extensively studied by [32,50]. More recently, the patterns of spatial distribution of firms focussed on logistics have also been studied [26]. Results reveal a mixed tendency of hierarchical and regional arrangement of cities in the studied context.

An important dimension of studying these networks is to identify densely connected regions often termed as clusters or communities. Based on network interactivity, or inter-dependency, cities and regions tend to favorably connect with others regardless of the geographical distances and boundaries [16,7]. For example, [32] applies hierarchical community detection along with alluvial diagrams to find hierarchical and temporal patterns respectively in city networks. [13] studied city networks to reveal hierarchical trends and regional patterns identifying clusters of cities with high connectedness. Multipolar regionalization of cities was studied by [42] with respect to multinational firms and the industrial sector the firms belong to. Many local and regional trends were observed with respect to how networks of cities are interconnected based on economic ties with varying industrial sectors.

The role of rising countries in the world trade network has also been studied by [28] where newer trade agreements have not only created an impact on trading partners but also lead to increasing regional trade. The authors are specifically interested in the role of BRIC countries (Brazil, Russia, India and China) in the world trade economy.

Cities and regions have also been studied with respect to identifying hubs and studying the resilience of these networks [5,37]. An interesting study (using the same data as this study) was conducted to model global economic crisis[20]. The authors concluded that out of the 12 countries most likely to initiate an economic crisis, only 6 are large economies. This is an interesting finding as the results show that weaker economies can also play a vital role in the global economic network.

The rise of cities in China and in the Gulf region is widely studied and accepted [2,33,14]. Although our findings re-assert this rise from the period of 2010 to 2013, our main objective is to identify other cities and regions across the world where this change has been significant.

A recent study identifies the criticality of countries based on three dimensions using the air transport network [48]. Their results reveal that some countries are important from all three dimensions (Network unweighted and weighted structure by passengers on direct lines or by ticket schedules) whereas others are influential in one or two dimensions. The results are somewhat similar to what we find with our data, considering cities instead of countries. We also find that the importance of cities depends on the network metrics being used.

3 Dataset

We used the multinational firms' networks of cities from the year 2010 and 2013. These networks were built by connecting two cities if they had financial ties between two firms belonging to the same group of companies. The financial ties mean firms owning a share of the capital of another company located in another city. Although we use the term cities here, they actually represent large urban areas that are delineated with the same standard criteria all around the world [42]. For example, Paris represents all the smaller towns and cities located around it. We selected the top 3,000 groups of companies worldwide and their 800,000 direct and indirect subsidiaries obtaining over 1 million links located around the globe each for the years 2010 and 2013. The top group of companies[2] were selected based on their annual turnover and the entire dataset is made available by Bureau van Dijk[3]. The data was extensively processed to clean incorrect fields and complete missing values as a collaboration between the Université de Lausanne (CitaDyne group) and the University of Paris (ERC GeodiverCity group)[4]. These networks are similar in construction but larger in size to other datasets [31,52,1] extensively used to represent economic networks of cities. Figure 1 depicts the construction of these networks. The figure explains the construction of the network using three groups of companies (Figure 1a namely Group 1 (Pink), Group 2 (Green) and Group 3(Dark Blue)) present in three different cities (namely City A (Yellow), City B (Red) and City C (Light Blue)). Figure 1b shows how the cities are linked based on the subsidiary linkages of the group of companies spread across different cities. Figure 1c shows how the links are aggregated to form a simple graph (without

[2] The term 'Group of Companies' or 'Corporate Group' refers to an economic entity formed from a set of companies which are either companies controlled by the same company, or the controlling company itself. In this contect, 'Controlling a Company' means having the power to appoint the majority of its directors [22]

[3] Source of Data : Bureau van Dijk Electronic Publishing (`http://www.bvdep.com/`)

[4] ORBIS 2010, 2013: BvD - Université de Lausanne (CitaDyne group) and University of Paris (ERC Geodiversity group)

multiple edges) between the cities. Table 1 shows a quantitative summary of the networks with common networks metrics.

The networks are structurally quite similar with very close values for average path length, transitivity and highest node degree. Average path length refers to how close two couples of cities are to each other. Transitivity refers to how many tuples of three cities are connected among themselves. Highest node degree is the maximum number of unique connections a city has with other cities. One important change between 2010 and 2013 is the increased number of nodes, which reflects the global economic strategy of firms progressing in their expansion. There are two implications of this change:

– Multinational companies opened new offices and/or acquired new companies to expand their presence in more cities;
– Multinational companies who were not in the list of top 3,000 have now risen in 2013 and thus added new cities to the network.

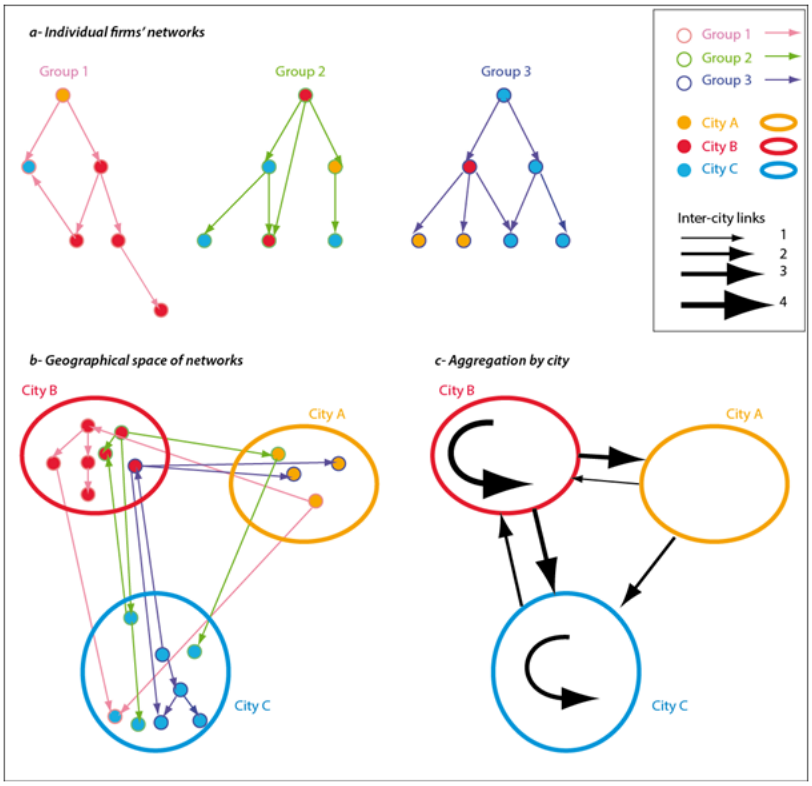

Fig. 1: Construction of Economic Networks of Cities: (a) Hierarchy of Multinational Firms and the links to their Subsidiaries (b) Firms are Geographically Distributed and (c) Links are aggregated to connect cities forming Economic Networks.

Table 1: Network Statistics: Quantitatively comparing the two networks. Different global metrics show the structural similarity of the two networks.

Metric	**2010**	**2013**
Cities (Represented by Nodes)	1206	1253
City-City Linkage (Unweighed Edges)	28639	31704
Node-Edge Ratio	23.7	25.3
Highest Degree	762	777
Average Path Length	2.29	2.27
Transitivity	0.331	0.339

4 Identifying Important Cities

We use three different notions to capture the importance of a city in a network: *Diversity*, *Strength* and *Centrality*. We define Diversity as a measure of importance of a city based on the number of connections it has to other unique cities[5]. So for example, City A has three connections to city B, and one connection to City C, in terms of diversity, we consider that city A has a diversity of two as it is connected to two unique cities. The more a city is connected to unique cities, the more diverse it will be considered.

In our context, Strength[6] reflects the total number of connections a city has in the network. Continuing with our example, City A would have a strength of four as it has a total of four connections, three with City B and one with City C. The higher the number of ties it has with other cities, the stronger it is in the network.

Finally, we define Centrality, which is probably the most widely used metric in social network analysis with numerous methods of calculation. The approach we have used in this paper to identify *central cities* is based on two ideas: One borrowed from *Global Production Network*[24] and *Global Value Chain*[21] used in spatial economics and: Second, borrowed from network connectivity[11] commonly used in social network analysis. We consider cities more central if they play a pivotal role in connecting the global network of cities. This in turn can be represented by cities which hold the network together as a single connected network. We estimate this by iteratively removing nodes from a network and evaluating their impact on its biggest connected component. This connectivity is critical in avoiding economic silos which hinder global trade and economic development thus putting cities with this characteristic in a central position. Our experiments on the two networks reveal that adaptive betwenneess centrality outperforms the other metrics in identifying the most central nodes.

[5] In terms of social network analysis, Diversity can be calculated using *Unweighed Degree Centrality*

[6] *Weighted Degree* can be used to calculate Strength

It is important to note that no single metric has been proven to be most effective in finding central nodes in different network topologies. Since centrality varies based on the topology and structure of a network [27,23,34], we applied several well-known metrics extensively used in the literature to find the optimal metric for each of the two city networks used in this study.

We used Degree [39], Betweenness Centrality [18], Eigenvector Centrality [9], Page-rank [38], K-core [6,55,3] and Collective Influence [36] as they are most widely used metrics. There are two well-known variations of using these centrality metrics and their impact on the largest connected component. The first calculates the metric once, and then simply keeps removing nodes in each iteration measuring its impact. The second re-calculates the metric with every removal, and then measures its impact. This later variation is called an *adaptive* calculation and has generally produced more effective results [36]. Algorithm 1 represents the adaptive variation to calculate central nodes representing cities for any given metric.

$G := graph(V, E)$;
$R_v := NULL$;
while $|V| > 0$ **do**
  $C := parameter(V)$;
  $max_v := v | v \in V, c_v \in C \wedge c_v = max(C_v)$;
  $G := graph(V - max_v, E)$;
  $R_v := |R| + 1$;
end
return R;

Algorithm 1: Adaptive variation to calculate central cities using any given metric

Figure 2 compares the performance of the various metrics on the two networks along with their adaptive variations. Figure 3 shows the progression of the iterative node removal process for the top four metrics. A metric is deemed to perform better than the other if it requires less number of iterations, which implies that less number of cities (nodes) where removed from the network to completely disintegrate it. Results clearly show that Adaptive Betweenness Centrality performs better in identifying Central nodes in both networks. This is partly consistent with the approach proposed by [25] where they provide an alternate network construction and use the classical Betweenness Centrality (as opposed to the adaptive version described here) to identify the importance of cities in the world city network. Based on these results, we have used adaptive betweenness as the metric to calculate *Central* cities in the two networks.

4.1 Cumulative Ranking of Cities

Since *Diversity*, *Strength* and *Centrality* all highlight the importance of a city in a specific context, we should not generalize cities' importance based solely on one metric. We identified these three metrics inspired from social network

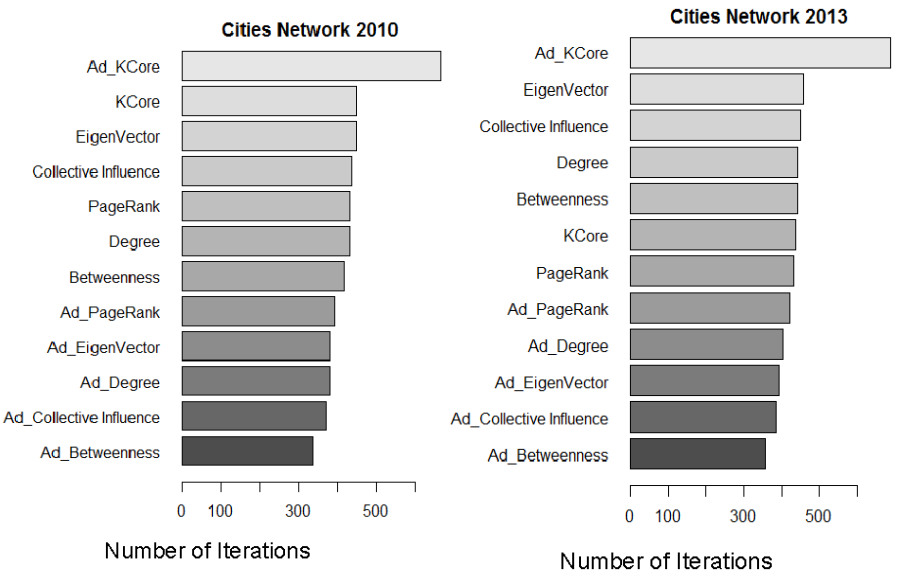

Fig. 2: Comparison of network metrics to identify the most effective method for networks of 2010 and 2013. Metrics are sorted by the lowest performing to the best performing from top to bottom. X-Axis represents the number of iterations (node removals) required to completely disintegrate the entire network. The prefix **Ad** with different metrics represents the adaptive version as explained in section 4.

analysis that significantly contribute in the economic development of cities. These metrics have formed the basis of many research studies to quantify the role and importance of cities in the world economy[1,14,42]. Since each of these metrics is important, we propose a cumulative rank (CR) combining all three to ensure a fair representation of various dimensions studied in this article. We equally weight the three metrics and calculate the harmonic mean using the equation:

$$CR_i = \frac{n}{\sum_{i=1}^{n} 1/x_i} \tag{1}$$

The harmonic mean of a city i given by CR_i is calculated by using the rank of city x for each of the three metrics ($n = 3$) such that x_1, x_2 and x_3 represent the rankings in the three metrics.

The cumulative rank ensures that the importance of a city is measured along three different dimensions and not just based on a particular metric. Equally weighing them gives equal importance to all three metrics used and thus provides us a unique and interesting way to estimate the global importance of a city.

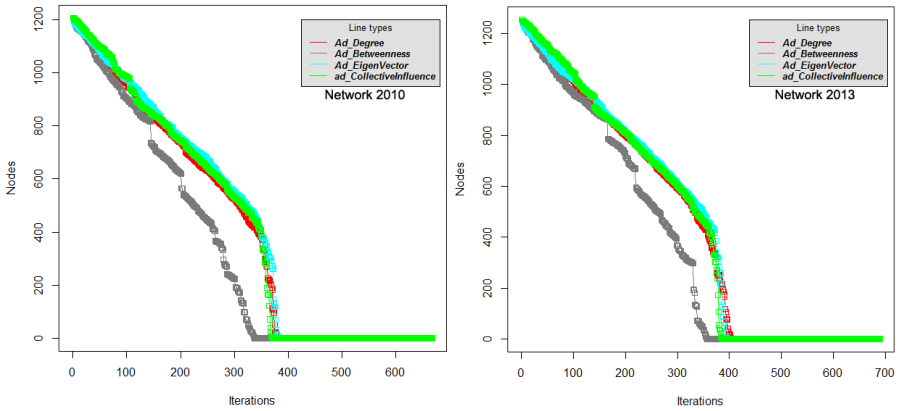

Fig. 3: Comparing the four best metrics to determine network connectivity. Adaptive Betweenness Centrality clearly outperforms other metrics as it is the quickest to disintegrate the entire network for both the years.

5 Results and Discussion

Figure 4 shows the *diversity* of cities in 2010 and 2013. The cities which are very close to the trend line have maintained their status from the year 2010 to 2013. Almost all the top cities like Paris, New York and Tokyo have shown this tendency which reflects that in terms of diversity, not much changed during the studied period. The cities which are far below the trend line have decreased in terms of diversity. Major cities affected in this way are Frankfurt, Copenhagen, Stockholm and Rome. Cities which are above the trend line such as Milan, Geneva and Baltimore have increased their diversity over the period and now have more connections to different cities. Cities of Scandinavia (like Copenhagen, Stockholm, or Goteborg) or cities of South (like Roma, Barcelona) mostly decreased while cities situated at the center like Zurich, Geneva, Milano, or Mannheim increased. Because of the crisis, networks have a tendency to concentrate in some geographic central cities, despite the observed exception of Frankfurt hosting the European central bank which had the opposite effect of weakening the city.

Also interesting mention here are the cities of Dubai and Abu Dhabi which have also increased considerably[7] representing growth in the Gulf region.

Figure 5 shows the *strength* of cities in 2010 and 2013. Again, the cities which are close to the trend line have preserved their status over the years with some major cities like Paris, New York and Amsterdam showing this tendency. The cities which are below the trend line have decreased in terms of *strength*. Major cities affected are Moscow, London, Frankfurt and Hong

[7] Appendix A, Table 5 and 6 contains the list of Top 25 Cities for Increased as well as Decreased *Diversity*

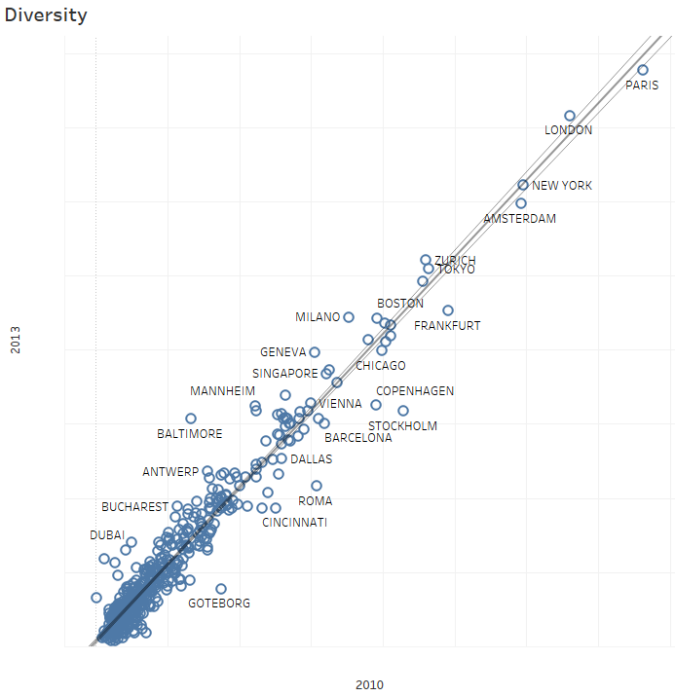

Fig. 4: Plotting *Diversity* of cities in 2010 (x-axis) against 2013 (y-axis). The cities which are very close to the trend line have maintained their status. Cities below the trend line have decreased diversity from 2010 to 2013 whereas cities above the trend line have increased diversity from 2010 to 2013.

Kong which are among the main financial centres in their own regions and it is interesting to see their decrease in strength. Cities which are above the trend line like Philadelphia, Milan, Chicago and Tokyo have increased their strength by increasing the weight of their connections to other cities. It is interesting to see a couple of cities from China (Beijing and Shanghai) in this list, as well as cities from Brazil (Sao Paulo) and Romania (Bucharest)[8].

Figure 6 shows the *centrality*[9] of cities in 2010 and 2013. The enlarged image on the right shows the top part for increased readability. The cities which are close to the trend line have similar centrality values for the two years with notable cities like Frankfurt, Brussels, Vienna, Chicago and Saint Petersbourg. Some of the cities which have decreased in terms of *centrality* are Goteborg (Sweden), Graz (Austria), Salt Lake City (USA) and Kuwait. Cities which have increased centrality include Dubai (UAE), Salzburg (Austria), Bal-

[8] Appendix A, Table 7 and 8 contains the list of Top 25 Cities for Increased as well as Decreased *Strength*

[9] Note that we have used adaptive betweenness to calculate centrality of cities as explained in section 4

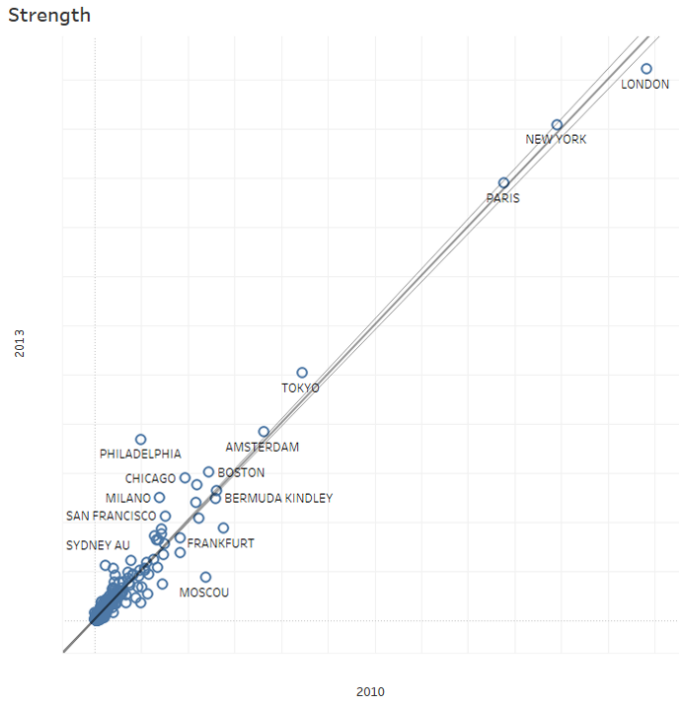

Fig. 5: Plotting *Strength* of cities in 2010 (x-axis) against 2013 (y-axis). The cities which are very close to the trend line have maintained their status. Cities below the trend line have decreased strength from 2010 to 2013 whereas cities above the trend line have increased strength from 2010 to 2013.

timore (USA) and Penang (Malaysia). It is interesting to note that there are a couple of cities each from Russia, Korea, China and United Arab Emirates in this list. Eastern Europe is also well represented by Akrotiri (Santorini in Cyprus), Gdansk (Poland), Tirana (Albania) and Vilnius (Lithuania) showing the emerging trend of these countries and regions[10].

Figure 7 shows the *cumulative rank* of cities in 2010 and 2013. The enlarged image on the right shows the top cities based on the cumulative ranking of the cities. The world's top cities can easily be identified with most of the top performers in 2010 retaining their position in 2013. Cities like Paris, London, New York and Tokyo have fairly stable positions in both years. It means that despite some smooth changes in each of the dimensions, largest cities maintain a very stable position. Milan, Geneva, San Francisco and Baltimore have improved their standings where cities like Stockholm, Frankfurt, Copenhagen and Barcelona have dropped their position.

[10] Appendix A, Table 9 and 10 contains the list of Top 25 Cities for Increased as well as Decreased *Centrality*

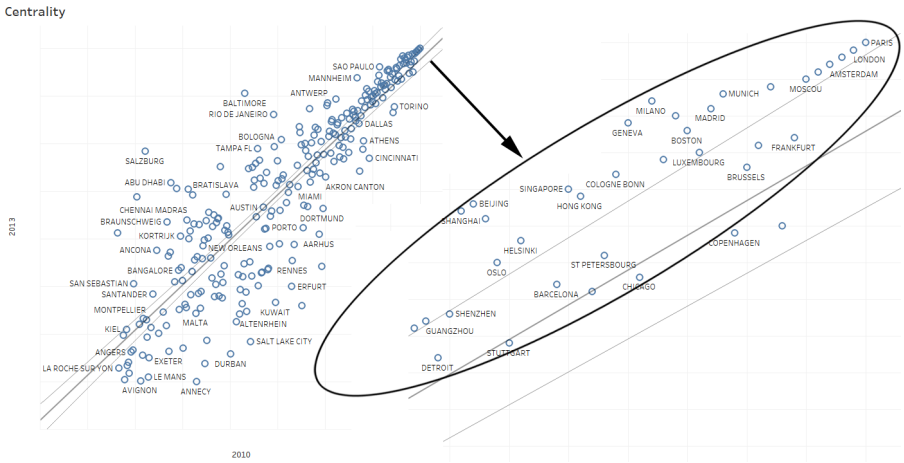

Fig. 6: Plotting *Centrality* of cities in 2010 (x-axis) against 2013 (y-axis). The image on the right enlarges the top cities. Again the cities which are very close to the trend line have maintained their status. Cities below the trend line have decreased centrality from 2010 to 2013 whereas cities above the trend line have increased centrality from 2010 to 2013.

Moving on from individual results, we summarize our findings in Figures 8, 9 and 10. We identify the cities which have been affected the most by the changes in global economic development of multinational firms from 2010 to 2013. Figure 8 and Table 2 show the top 25 cities from the years 2010 and 2013. Three regions clearly stand out from the geographical perspective, North America, Western Europe and Eastern Asia. Moscow (Russia) and Sydney (Australia) are also among the top cities in the world. It is interesting to note that cities from South America, all of Africa, South Asia and the Gulf are not part of this list.

Figure 9 and 10 show the cities with the most positive and negative impact over the studied period. Comparing these cities with the top cities (Figure 8) reveal how the world economy is changing in the context of multinational firms.

Cities with the highest positive change in their cumulative rank are well spread across the globe with most cities from the Western European region and North America. Cities from Germany (Mannheim, Hanover), UK (Jersey, Guernsey), Italy (Milan, Bologna), Austria (Salzburg) and Belgium (Antwerp) demonstrate a strong development in the Western European region. Baltimore, Phoenix, Tampa and Kansas City show growth in the USA which are mostly second tier cities. Two cities from Cyprus (Akrotiri [Santorini], Nicosia) present an interesting development in the region. This is due to many Russian investments transiting by these cities to the cities of the European core. Countries from Eastern Asia are represented by China (Beijing) and Japan (Yokohama). Specially Beijing, which begins to catch up Hong-Kong outstrip-

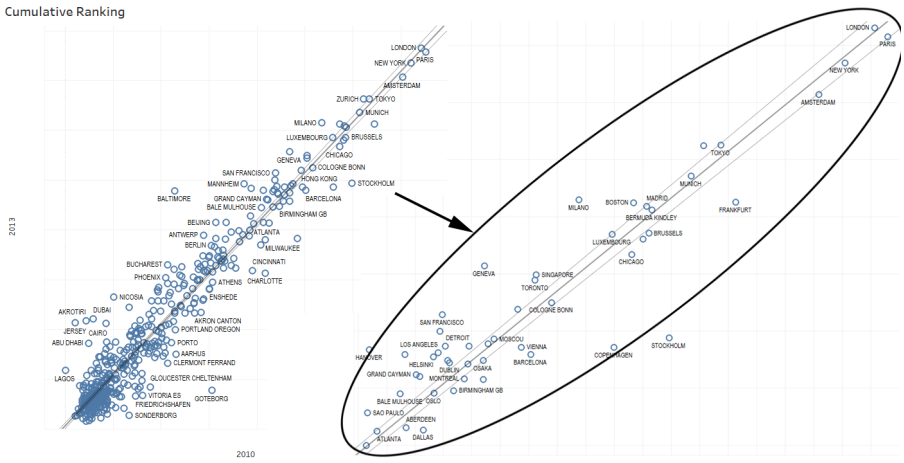

Fig. 7: Plotting *Cumulative Rank* of cities in 2010 (x-axis) against 2013 (y-axis). The image on the right shows the top cities zoomed-in. Again the cities which are very close to the trend line have maintained their status. Cities below the trend line have decreased the cumulative rank from 2010 to 2013 whereas cities above the trend line have increased cumulative rank from 2010 to 2013.

ping Shanghai in a centralized economic and political process. Egypt (Cairo) and United Arab Emirates (Dubai, Abu Dhabi) represent Africa and the Gulf region. It is interesting to note that developing nations such as Brazil (Rio de Janeiro), Nigeria (Lagos) and Turkey (Istanbul) are also represented by their cities with their growing economies. Comparing these results with cities from Figure 8, we can clearly observe that growth in Lagos, Cairo, Dubai, Abu Dhabi, Istanbul and Bucharest will have a positive impact on the economies of their respective countries.

Cities with the highest negative change in their cumulative rank are mostly concentrated in the United States of America and Western Europe. Cities in the USA are well spread across different states mostly on the east coast and the center. Cities in Western Europe are also well spread among various countries traditionally considered as strong economies such as Germany (Friedrichshafen, Dortmund), France (Clermont-Ferrand, Annecy), Denmark (Sonderborg, Copenhagen, Aarhus), Sweden (Goteborg, Stockholm) and Italy (Rome, Siena). Two exceptions in this list are Kuwait City (Kuwait) and Chelyabinsk (Russia). It is important to understand that most of the cities that have decreased their rank are not the strongest cities with respect to the presence of multinational firms. Thus, this decline has not created any considerable impact on the overall national and regional economic development.

The two most important findings from this research are: First, the cities that had the highest positive change are spread all over the world, which shows a global development trend; and second, the cities that were dominant in 2010

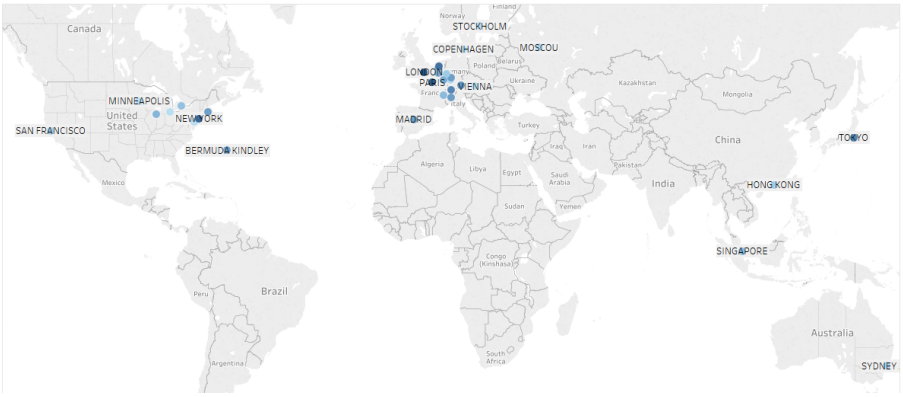

Fig. 8: Top cities in the year 2010 and 2013 based on Cumulative Ranking.

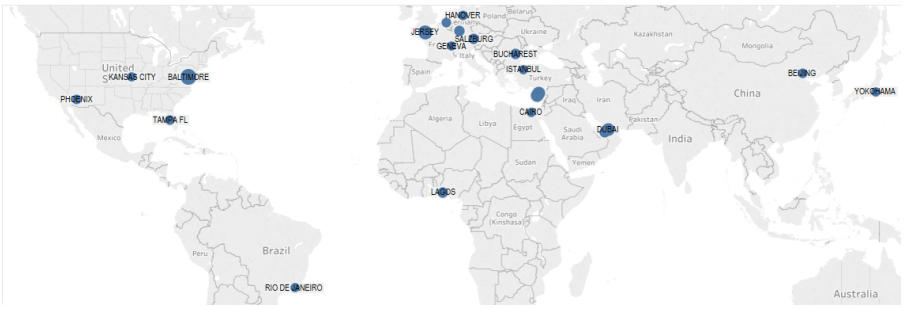

Fig. 9: Top cities with positive change in cumulative rankings from 2010 to 2013.

Table 2: List of Top 25 Cities Based on Cumulative Rank in 2010 and 2013

Rank	City	Country	Region	Rank	City	Country	Region
1.	Paris	France	Western Europe	14.	Luxembourg	Luxembourg	Western Europe
2.	London	Germany	Western Europe	15.	Chicago	USA	North America
3.	New York	USA	North America	16.	Stockholm	Sweden	Western Europe
4.	Amsterdam	Netherlands	Western Europe	17.	Singapore	Singapore	Eastern Asia
5.	Tokyo	Japan	Eastern Asia	18.	Toronto	Canada	North America
6.	Zurich	Switzerland	Western Europe	19.	Copenhagen	Denmark	Western Europe
7.	Frankfurt	Germany	Western Europe	20.	Cologne Bonn	Germany	Western Europe
8.	Munich	Germany	Western Europe	21.	Geneva	Switzerland	Western Europe
9.	Bermuda Kindley	Bermuda	Caribbean	22.	Hong Kong	Hong Kong	Eastern Asia
10.	Madrid	Spain	Western Europe	23.	Barcelona	Spain	Western Europe
11.	Boston	USA	North America	24.	Vienna	Austria	Western Europe
12.	Brussels	Belgium	Western Europe	25.	Moscow	Russia	Eastern Europe
13.	Milan	Italy	Western Europe				

retain their dominance in 2013 for all the regions, but inside these regions, inequaities increase. It could be interpreted as a transformation of the different regional subsystems of cities that were outlined by [42] as encompassing most of 75% of the multinational ownership linkages: North America, Europe

Table 3: List of Cities with Highest Positive Change in Cumulative Rank

Rank	City	Country	Region	Rank	City	Country	Region
1.	Baltimore	USA	North America	14.	Hanover	Germany	Western Europe
2.	Jersey	UK	Western Europe	15.	Phoenix	USA	North America
3.	Akrotiri	Cyprus	Eastern Europe	16.	Tampa	USA	North America
4.	Nicosia	Cyprus	Eastern Europe	17.	Rio de Janeiro	Brazil	South America
5.	Dubai	UAE	Western Asia	18.	Geneva	Switzerland	Western Europe
6.	Guernsey	UK	Western Europe	19.	Cairo	Egypt	North Africa
7.	Abu Dhabi	UAE	Western Asia	20.	Yokohama	Japan	Eastern Asia
8.	Mannheim	Germany	Western Europe	21.	Kansas City	USA	North America
9.	Lagos	Nigeria	Western Africa	22.	Istanbul	Turkey	Eastern Europe
10.	Bucharest	Romania	Eastern Europe	23.	Milan	Italy	Western Europe
11.	Salzburg	Austria	Western Europe	24.	Shanghai	China	Eastern Asia
12.	Beijing	China	Eastern Asia	25.	Bologna	Italy	Western Europe
13.	Antwerp	Belgium	Western Europe				

Fig. 10: Top cities with negative change in cumulative rankings from 2010 to 2013.

Table 4: List of Cities with Highest Negative Change in Cumulative Rank

Rank	City	Country	Region	Rank	City	Country	Region
1.	Goteborg	Sweden	Western Europe	14.	Tulsa	USA	North America
2.	Sonderborg	Denmark	Western Europe	15.	Graz	Austria	Western Europe
3.	Charlotte	USA	North America	16.	Kuwait	Kuwait	Western Asia
4.	Stockholm	Sweden	Western Europe	17.	Chelyabinsk	Russia	Eastern Europe
5.	Rome	Italy	Western Europe	18.	Jacksonville	USA	North America
6.	Vitoria	Spain	Western Europe	19.	Salt Lake City	USA	North America
7.	Gloucester Cheltenham	UK	Western Europe	20.	Kaliningrad	Russia	Eastern Europe
8.	Shannon	Ireland	Western Europe	21.	Omaha	USA	North America
9.	Clermont Ferrand	France	Western Europe	22.	Albany	USA	North America
10.	Aarhus	Denmark	Western Europe	23.	Siena	Italy	Western Europe
11.	Friedrichshafen	Germany	Western Europe	24.	Dortmund	Germany	Western Europe
12.	Copenhagen	Denmark	Western Europe	25.	Annecy	France	Western Europe
13.	Cincinnati	USA	North America				

and Africa, Great Britain and Commonwealth, Iberia and South America, Japan, East Asia and India. These transformations are merely a relative deconcentration of the centrality to emerging regions (like China and middle East) but in the previous dominant regions (like US and Europe), the rise of some cities that faced the crisis better than others.

Cities are specialized in some functions like Geneva in finance, German cities in industry and transportation for Europe, Phoenix for high-tech industry or Baltimore with its harbor zone, the new warehouse of Amazon and the new headquarters for Under Armour. Particularly Baltimore which emerges as the top city with the highest positive change is continuously surging as a

growing economy. Baltimore's property wealth has grown over the said time period and is still well above the rest of the state of Maryland. Similarly Jersey has shown a continuous growth with its strong economic activity in financial services as the island is considered to be one of the leading offshore financial centres. Mannheim, Germany is also among the top cities with positive change and is a well-known center of invention and progress. Mannheim's medical technology sector has and currently is one of the biggest driving force of this change besides the automobile sector of Volkswagen. The city hosts the headquarters of several global medical technology players such as Roche Diagnostics, DENTSPLY Friadent, VRmagic and Siemens Healthcare. Bologna (Region of Emilia Romagna) in Italy boosts the regions growth with its manufacturing industry with big names such as Ferrari, Lamborghini, Ducati. The regions economy shrank around the crisis in 2010-2012 but has since seen a consistent growth mainly attributed to its healthy exports.

In addition, the rise of the Asian cities and especially those in China have had a major negative impact on Hong-Kong which is not surprising. The Gulf cities, diversify economically with air traffic, finance and high-tech. This diversification has helped the cities sustain through the crisis and eventually have a positive change in their economies. The two rising African metropolises (Lagos and Cairo) also begin to catch upto the level of regional capitals, leading their regions in global integration.

Generally, cities having the highest negative change did not change the whole globalization as they are well spread all over the world. They only decline in their own sub-regional system having minimal global impact. For example, the city of Goteborg (Sweden) saw steep decline in its economy which hit its worst in spring 2009 resulting in high unemployment. The city started to recover around 2014 and has since seen a positive growth. The city has seen a change in focus from the manufacturing industry with Volvo and Ericsson as the key employers to high-tech industries which have now stablized the growth of the city. Stockholm, Sweden is another perfect case where the country's tremendous growth during the period of 2008-2010 slowed down in the period 2010-2013. Since 2013, we have seen a continuous growth in Sweden's GDP growing at a better rate than several economic giants such as USA, UK and Germany. Stockholm's success stems from five major sectors, Trade in high-tech industries (refined petroleum products, electronics, chemicals, and transportation equipment), Innovation with a high number of patents with commercial and university-industry partnerships, Talent with highly educated work-force, Infrastructure (top quality freight, aviation, and broadband systems) and Governance which ensures that the policies support business success. Sodenborg, Denmark with Danfoss group is a global player in product and services industry (primarily cooling and heating products). Sodenborg and subsequently the Danish economy has not been performing well over for several years with annual growth reportedly to be the lowest around 1.1% in the year 2016. This slow growth has mainly been attributed to the weak domestic production growth.

We discussed insights and details of a few cities from both the sets of cities with the highest positive and negative change. There are several factors that result in this change such as global economics, urban development, regional policies, international politics and social capital. Besides the general crisis affecting the whole cities' network by a concentration in most of the former dominant regions, and the rise of new cities in emerging countries, the main factor explaining why some cities faced the crisis better than others can be found in their specialization in some growing economic sectors.

6 Conclusions and Future Work

In this paper, we have studied the networks of multinational firms from the world's top 3,000 group of companies from the year 2010 and 2013. Comparing them based on *Diversity*, *Strength* and *Centrality* we have identified the cities with the most positive and negative change during the said period. Based on these metrics, we have proposed a *Cumulative Ranking* of the cities and identified the most important cities around the world as well as the cities which increased/decreased their position in the world economy. Our results ascertain many known findings about world's top cities like New York, London, Paris and Tokyo but also identify growing economies in some of the developing regions in the world like Cairo, Dubai, Abu Dhabi, Rio de Janeiro, Lagos, Istanbul and Bucharest.

This work only presents a big picture on how the cities were impacted during the period between 2010 and 2013. This can lay an initial foundation to further explore insights into more precise industrial sectors. In fact, economic cycles favor cities able to develop them before the other cities. Thus, an interesting future extension could be the study of these evolution on longer periods of time by activity sectors and their comparisons in order to evaluate the effects of these cycles on the diffusion/concentration processes among cities [40]. This would bring a better comprehension of the evolution of the worldwide system of cities through their economic networks.

7 Acknowledgements

The authors would like to thank Jamie Barnes from the Region of Peel for his valuable insights to improve the manuscript. We would also like to thank the anonymous reviewers for their valuable input which allowed us to significantly improve the quality of this manuscript.

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A Appendix

A.1 Network Metrics for Centrality

In this appendix, we define the various network metrics used in Section 6 to identify 'Central Nodes'.

Degree Centrality[39] is one of the earliest metrics used to measure the centrality of a node. Degree refers to the number of direct connections a node has in the network. The more the node is connected, the more central it will be. Subsequently, many new metrics have been developed to suit the requirements of specific applications, as graph theory and network analysis became popular in various other fields. We use degree not only to calculate *Strength* but also as a measure of *centrality*. This is in order to compare the performance of other centrality metrics with degree centrality as it is one of the most widely used metrics in social network analysis.

Betweenness Centrality[18] of a node is the number of times it appears in calculating shortest paths among other pairs of nodes. In other words, the nodes which are structurally located *between* other nodes get a higher rank. Betweenness centrality is a centrality measure taking into account the whole network, thus a global centrality measure.

Eigenvector centrality [9] is a measure of influence of a node which is calculated by recursively calculating the relative importance of a node's neighbors. A node is considered important if it is connected to other important nodes. Google's PageRank algorithm proposed by Larry Page [38] is a variant of Eigenvector centrality. It assigns a weight to each node in a network according to its relative importance (similar to eigenvector centrality) but has additional features to avoid some of the pitfalls of its predecessor. The underlying assumption of pagerank is that important websites are likely to receive more connections from other websites, and has been very effective in identifying influential websites.

K-Core centrality[6] gained a lot of popularity particularly the analysis of protein interaction networks [55]. Apart from its utilization in analysis, it has also been used to visualize large scale networks as it decomposes a network into subsets of vertices of increasing centrality. It can also help focus on certain regions of interest in a network [3]. The method consists of identifying subsets of the network called k-cores. These subsets are obtained by recursively removing all the vertices of degree smaller than k, until the degree of all remaining vertices is larger than or equal to k. Cores with larger values of k correspond to sets of vertices with high degree that are connected to high degree vertices only. This gives cores with larger values of k a more central position in the network's structure [3].

A recent advancement in identifying influential nodes is the introduction of the metric CI (collective influence)[36] which exploits the fact that individual selection of nodes does not result in an optimal set of influential nodes in a network. Rather, it is a many-body problem and thus requires it to be modeled as an optimal percolation problem[36]. Thus, the influence or centrality we intend to focus on in this paper can be described as the search of the minimal optimal set that ensures network level cohesiveness[29,36]. In the context of economic networks of cities, this represents the set of cities that enables global connectivity in the overall network.

Collective Influence (CI) [36] is claimed to be the best metric in the context of network resilience and connectivity but it has never been compared with an adaptive version of betweenness centrality. This is due to the high asymptotic time complexity of using adaptive betweenness centrality which is of the order of $O(n^3)$ as compared to the low complexity of CI which is linear in terms of number of edges in the network. Since our objective is not to find the fastest metric, but to find the best metric in terms of effectiveness, we discover that at least for these two city networks, adaptive betweenness centrality clearly outperforms CI.

A.2 Detailed Results for Diversity, Strength and Centrality

Table 5: List of Top 25 Cities with Increased Diversity

Rank	**City**	**Country**	**Region**
1.	Baltimore	United States of America	North America
2.	Jersey	United Kingdom	Western Europe
3.	Mannheim	Germany	Western Europe
4.	Hanover	Germany	Western Europe
5.	Geneva	Switzerland	Western Europe
6.	Milan	Italy	Western Europe
7.	Nicosia	Cyprus	Eastern Europe
8.	Dubai	United Arab Emirates	Western Asia
9.	Akrotiri	Cyprus	Eastern Europe
10.	Antwerp	Belgium	Western Europe
11.	Bucharest	Romania	Eastern Europe
12.	San Francisco	United States of America	North America
13.	Beijing	China	Eastern Asia
14.	Abu Dhabi	United Arab Emirates	Western Asia
15.	Lagos	Nigeria	Western Africa
16.	Phoenix	United States of America	North America
17.	Zurich	Switzerland	Western Europe
18.	Maastricht	Netherlands	Western Europe
19.	Tampa	United States of America	North America
20.	Shanghai	China	Eastern Asia
21.	Sydney	Australia	Australia/Oceania
22.	London	United Kingdom	Western Europe
23.	Kansas City	United States of America	North America
24.	Cleveland	United States of America	North America
25.	Yokohama	Japan	Eastern Asia

Table 6: List of Top 25 Cities with Decreased Diversity

Rank	City	Country	Region
1.	Stockholm	Sweden	Western Europe
2.	Goteborg	Sweden	Western Europe
3.	Rome	Italy	Western Europe
4.	Copenhagen	Denmark	Western Europe
5.	Charlotte	United States of America	North America
6.	Sonderborg	Denmark	Western Europe
7.	Cincinnati	United States of America	North America
8.	Aarhus	Denmark	Western Europe
9.	Munster	Germany	Western Europe
10.	Frankfurt	Germany	Western Europe
11.	Clermont Ferrand	France	Western Europe
12.	Dundee	United Kingdom	Western Europe
13.	Shannon	Ireland	Western Europe
14.	Torino	Italy	Western Europe
15.	Novosibirsk	Russia	Eastern Europe
16.	Angouleme	France	Western Europe
17.	Kuwait	Kuwait	Western Asia
18.	Omaha	United States of America	North America
19.	Porto	Portugal	Western Europe
20.	Friedrichshafen	Germany	Western Europe
21.	Siena	Italy	Western Europe
22.	Perm	Russia	Eastern Europe
23.	Akron Canton	United States of America	North America
24.	Milwaukee	United States of America	North America
25.	Vitoria	Spain	Western Asia

Table 7: List of Top 25 Cities with Increased Strength

Rank	City	Country	Region
1.	Philadelphia	United States of America	North America
2.	Milan	Italy	Western Europe
3.	Chicago	United States of America	North America
4.	Baltimore	United States of America	North America
5.	Beijing	China	Eastern Asia
6.	San Francisco	United States of America	North America
7.	Tokyo	Japan	Eastern Asia
8.	Zurich	Switzerland	Western Europe
9.	Boston	United States of America	North America
10.	Lille	France	Western Europe
11.	Sydney	Australia	Australia/Oceania
12.	Los Angeles	United States of America	North America
13.	Singapore	Singapore	Eastern Asia
14.	Shanghai	China	Eastern Asia
15.	Luxembourg	Luxembourg	Western Europe
16.	Houston	United States of America	North America
17.	Grand Cayman	Cayman Islands	Caribbean
18.	Mannheim	Germany	Western Europe
19.	Detroit	United States of America	North America
20.	Geneva	Switzerland	Western Europe
21.	Sao Paulo	Brazil	South America
22.	Denver	United States of America	North America
23.	Toronto	Canada	North America
24.	Bucharest	Romania	Eastern Europe
25.	Bologna	Italy	Western Europe

Table 8: List of Top 25 Cities with Decreased Strength

Rank	City	Country	Region
1.	Moscou	Russia	Eastern Europe
2.	Frankfurt	Germany	Western Europe
3.	Stockholm	Sweden	Western Europe
4.	London	United Kingdom	Western Europe
5.	Charlotte	United States of America	North America
6.	Dusseldorf	Germany	Western Europe
7.	Munich	Germany	Western Europe
8.	Copenhagen	Denmark	Western Europe
9.	Cologne	Germany	Western Europe
10.	Milwaukee	United States of America	North America
11.	Birmingham	United Kingdom	Western Europe
12.	Saint Petersbourg	Russia	Eastern Europe
13.	Leeds	United Kingdom	Western Europe
14.	Barcelona	Spain	Western Europe
15.	Hong Kong	Hong Kong	Eastern Asia
16.	Manchester	United Kingdom	Western Europe
17.	Goteborg	Sweden	Western Europe
18.	Osaka	Japan	Eastern Asia
19.	Rotterdam	Netherlands	Western Europe
20.	Samara	Russia	Eastern Europe
21.	Nuremberg	Germany	Western Europe
22.	Glasgow	United Kingdom	Western Europe
23.	Southhampton	United Kingdom	Western Europe
24.	Bermuda Kindley	Bermuda	North America
25.	Novosibirsk	Russia	Eastern Europe

Table 9: List of Top 25 Cities with Increased Centrality

Rank	City	Country	Region
1.	Akrotiri	Cyprus	Eastern Europe
2.	Nizhniy Novgorod	Russia	Eastern Europe
3.	Dubai	United Arab Emirates	Western Asia
4.	Ekaterinburg	Russia	Eastern Europe
5.	Guernsey	United Kingdom	Western Europe
6.	Gdansk	Poland	Eastern Europe
7.	Salzburg	Austria	Western Europe
8.	Tampere	Finland	Western Europe
9.	Tirana	Albania	Eastern Europe
10.	Taegu	Republic of Korea	Eastern Asia
11.	Fuzhou	China	Eastern Asia
12.	Tianjin	China	Eastern Asia
13.	Jersey	United Kingdom	Western Europe
14.	Vilnius	Lithuania	Eastern Europe
15.	Ciudad Juarez	Mexico	Central America
16.	Baltimore	United States of America	North America
17.	Barbados	Barbados	Caribbean
18.	Chengdu	China	Eastern Asia
19.	Reims	France	Western Europe
20.	Penang	Malaysia	Eastern Asia
21.	Pusan	Republic of Korea	Eastern Asia
22.	Abu Dhabi	United Arab Emirates	Western Asia
23.	Xiamen	China	Eastern Asia
24.	Cairo	Egypt	North Africa
25.	Curitiba	Brazil	South America

Table 10: List of Top 25 Cities with Decreased Centrality

Rank	City	Country	Region
1.	Goteborg	Sweden	Western Europe
2.	Sonderborg	Denmark	Western Europe
3.	Kaliningrad	Russia	Eastern Europe
4.	Chelyabinsk	Russia	Eastern Europe
5.	Vitoria	Spain	Western Europe
6.	Gloucester Cheltenham	United Kingdom	Western Europe
7.	Oulu	Finland	Western Europe
8.	Bergen	Norway	Western Europe
9.	Friedrichshafen	Germany	Western Europe
10.	Graz	Austria	Western Europe
11.	Shannon	Ireland	Western Europe
12.	Jinan	China	Eastern Asia
13.	Winnipeg	Canada	North America
14.	Matsumoto	Japan	Eastern Asia
15.	Zhuhai	China	Eastern Asia
16.	Ostend	Belgium	Western Europe
17.	Clermont Ferrand	France	Western Europe
18.	Tulsa	United States of America	North America
19.	Salt Lake City	United States of America	North America
20.	Parma	Italy	Western Europe
21.	Durban	South Africa	Southern Africa
22.	Kuwait	Kuwait	Western Asia
23.	Erfurt	Germany	Western Europe
24.	Annecy	France	Western Europe
25.	Murcia	Spain	Western Europe